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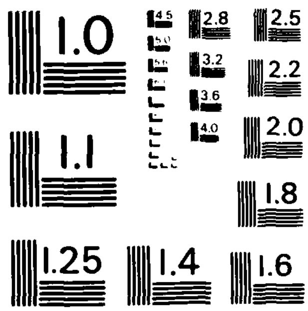

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REPRESENTATION OF INFORMATION IN SOFTWARE DOCUMENTATION

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This report describes a series of six experiments designed to evaluate the performance of programmers using different forms of software documentation. The results from the first five experiments suggested that for sequential programs, succinct symbology leads to better performance than English prose, and a branching spatial arrangement provides the clearest display of control flow. The final experiment suggested that the most appropriate type of documentation for concurrent programs is different than

the most appropriate type of documentation for strictly sequential programs. For simple programs and simple modifications, it was not crucial whether interprocess communications or control-flow information was highlighted in the documentation format. For more complex problems, it appeared that control-flow information was not necessary, and, in fact, may have interfered with performance.

This report also describes the contents of the book Human Factors in Computer Systems. This book is being published by Ablex Publishers and it contains several papers selected from the conference held in Gaithersburg, Maryland in March 1982.

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INTRODUCTION

For the past four years (1 AUG 79 - 15 JUL 83), we have been examining the nature of software documentation. The efficiency with which programming tasks are performed is determined in part by how thoroughly a programmer understands the design or function of the system under consideration. The thoroughness of a programmer's understanding, in turn, depends heavily on the quality of the documentation available. The research we conducted was therefore involved in identifying and validating human engineering principles to improve the ability of documentation to assist programmers in understanding programming systems.

Our approach to evaluating different forms of documentation was to investigate how various characteristics of presentation affect the performance of programmers on typical software-related tasks. There are two primary dimensions for categorizing how available documentation aids configure the information they present to programmers: the type of symbology in which information is presented, and the spatial arrangement of that information. The interrelation of these two dimensions describes generic types of documentation not necessarily embodied in existing techniques. The symbology dimension includes narrative text, constrained language, and ideograms. The spatial arrangement of information dimension was represented by sequential, branching, and hierarchical arrangements.

EXPERIMENTS

In this research program, we completed four experiments to investigate the effects of the type of symbology and the spatial arrangement. In the first experiment (Tech. Rep. 80-388200-2), 72 professional programmers were presented with documentation for each of three modular-sized computer programs. The participants answered a series of comprehension questions for each program using only the documentation (i.e., they were not given the actual program listing). The questions were presented interactively on a CRT and consisted of three different types. For forward-tracing questions, the participants were given the values for a set of conditions in the program. Their task was to trace through the documentation and find the first statement executed under those conditions. For backward-tracing questions, they were required to locate a given statement within the documentation and then determine the set of conditions which led to that point. For the input-output questions, they were given input data and were asked to determine the value of particular variables at a later point in the program.

Both forward and backward-tracing questions were answered more quickly from documentation presented in PDL or ideograms than in normal English. On the average, forward-tracing questions were answered most quickly from a branching arrangement and backward-tracing questions were answered more quickly from the branching and hierarchical arrangements. An examination of the individual formats revealed that the sequential PDL, the branching PDL, and the branching ideogram versions were associated with very quick responses for both types of questions. For the input-output questions, no significant differences were found as a function of the type of symbology or the spatial arrangement. At the conclusion of the experimental session, participants were asked to list the type of symbology and the spatial arrangement they most preferred. PDL was the most preferred symbology and the branching spatial arrangement was the most preferred arrangement.

In the second experiment (Tech. Rep. 81-388200-3), 36 professional programmers were presented with documentation and partially completed code for the same three programs. The participants constructed a major section of code at the middle of each program. About fifteen lines were missing from the code. This section included the most complex decision structures present in the program.

Substantial differences in performance were associated with the type of symbology. Coding from the normal English formats took considerably longer (29.7 minutes) than coding from the PDL (20.5

minutes) or ideogram (23.9 minutes) versions. An examination of the error data showed a similar pattern: the normal English formats resulted in a mean of 2.4 errors, the PDL resulted in 0.8 error and the ideograms resulted in 1.4 errors.

The effect of spatial arrangement was not as great as the effect of symbology. Although not statistically significant, the branching arrangement appeared to be superior to the sequential and hierarchical arrangements, particularly in minimizing errors related to the control flow. A comparison of the individual formats revealed that the sequential PDL and the branching PDL resulted in the highest level of performance. The branching ideograms and the hierarchical ideograms were also associated with good performance. Of the nine formats, the sequential normal English version resulted in the lowest level of performance.

The participants' preferences for symbology and spatial arrangement were consistent with the time and error data. PDL was the symbology preferred most often and branching was the most preferred spatial arrangement.

In the third experiment (Tech. Rep. 81-388200-4), 36 professional programmers were asked to compare error-seeded program code to the same documentation formats in order to detect and correct the errors. There were three errors per program. These errors were selected from among those made during the coding task in Experiment 2. The participants were told that the errors were located in the center section of the programs but they were not told how many errors occurred in each program. The dependent variable was time to debug.

Again, substantial differences in performance were associated with the type of symbology. Debugging from normal English took longer (18.7 minutes) than debugging from either PDL (14.5 minutes) or ideograms (14.2 minutes). The overall effect of spatial arrangement was not pronounced. A comparison of the individual formats revealed that the sequential and branching PDL again led to a high level of performance as did the branching and hierarchical ideograms. The sequential normal English again resulted in very poor performance.

The participants had no preferences for the type of symbology but did prefer the branching spatial arrangement to the sequential and hierarchical arrangements.

In the first three experiments, normal English resulted in substantially longer response times than the other two symbologies. It appeared likely that at least part of this difference was due to the manner in which variable names were expressed. The normal English contained an English description of each variable while the PDL and ideograms contained the variables as they were used in the FORTRAN code. Thus, the normal English required more translation from the documentation to the code.

In the fourth experiment (Tech. Rep. 81-388200-5), an abbreviated English was substituted for the ideograms in order to assess the extent to which the variable names account for the symbology effect. The abbreviated English was identical to the normal English with the exception that the variable names were used rather than normal English descriptions. Thus, the abbreviated English was more succinct than the natural language but less succinct than the PDL.

The task in this experiment was to modify the three programs. The modifications required a minimum of three to five lines of additional code. Performance was measured by the time to code and debug the modifications and by the number of errors.

Although the effect of type of symbology was not pronounced in this experiment, the results reflected the trend that appeared quite strongly in the previous three experiments. The more succinct symbology, the PDL, was associated with better performance than the more verbose symbology, the normal English. The effect of spatial arrangement was quite strong in this experiment. The branching arrangement was considerably better for the modification task than the other two arrangements.

The participants' preferences for type of symbology and spatial arrangement in this experiment are consistent with preferences from the other experiments. PDL was the preferred symbology and branching was the preferred spatial arrangement.

The first four experiments in this series, then, produced slightly different results, depending on the type of experimental task: answering questions, coding, debugging, or modifying programs. That is, no one particular combination of symbology and spatial arrangement proved superior for all tasks. However, there was a sufficient degree of consistency to allow the formulation of two general principles to characterize the overall effects of symbology and spatial arrangement:

(1) the more succinct the symbology, the better the performance, and

(2) the branching arrangement provides the clearest display of control flow. (An example of the PDL branching documentation can be seen in Figure 1.)

The results from these experiments suggested that PDLs are the optimal documentation format for coding. The question that arose was why this form of documentation was superior to the other formats tested. The most probable explanation of this superiority was that PDL was the most code-like of all documentation formats tested. As a result, there is less translation required in mapping between the documentation and the code. If the amount of translation is a critical underlying factor, no single form of PDL will be optimal for all implementation languages. Rather, the optimal PDL will be one that is tailored toward the particular implementation language.

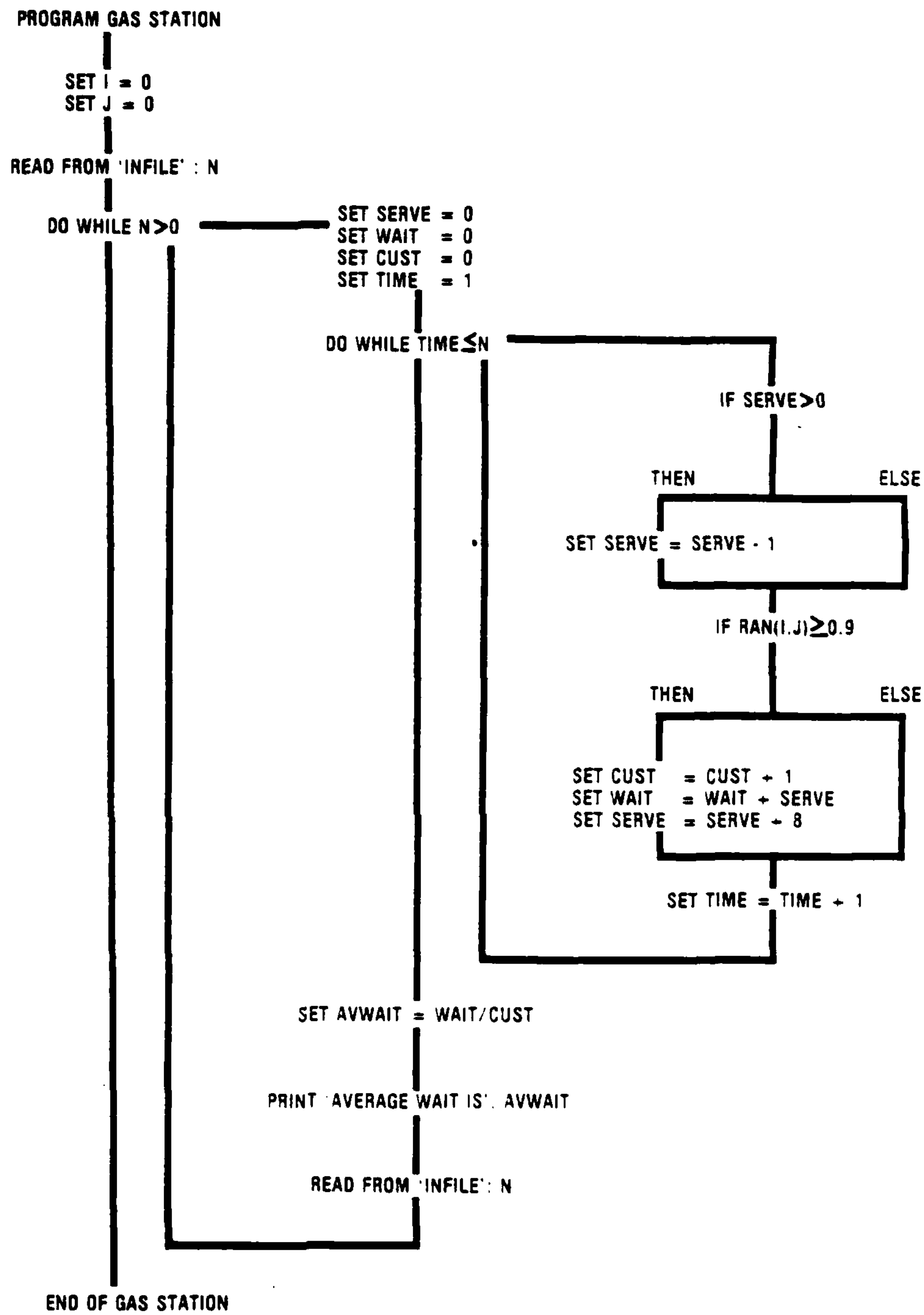

Figure 1. PDL Branching

A fifth experiment (Tech. Rep. 82-388200-6) was therefore conducted to determine the effectiveness of using a PDL specifically designed to aid in coding the corresponding implementation language. This was done by designing PDLs which reflected the syntax and features of several languages and examining the performance of programmers coding from these various PDLs in one of two implementation languages.

Twenty-four programmers were presented with three programs from which several lines had been deleted. Their task was to complete the code for each program in either FORTRAN or MACRO-11 (PDP-11 assembly language). Performance was measured by the time to code and debug the missing segment of code and by the number of errors.

The results from this experiment helped to shed light on our earlier finding of a substantial advantage for PDL over other formats. In this experiment, the fastest coding times occurred when there was a match between the PDL implementation language and the coding language, that is, using a MACRO-11 PDL when coding in MACRO-11 and using a FORTRAN PDL when coding in FORTRAN. This suggests that PDLs produced superior performance in our earlier studies since they required less translation in going from the design to the code than the other formats we tested.

The sixth and final experiment in this research program (Tech. Rep. 83-388200-7) extended the previous research from purely sequential programs into the domain of concurrent programming by examining performance on a modification task. The investigation of documentation for concurrent processing is especially important since this form of processing is used extensively in embedded computer systems which must monitor and control a number of hardware interfaces simultaneously. Embedded software now consumes over half of the Department of Defense software budget. Examples of embedded applications include systems for missile guidance, aircraft flight control, and multiplexing of communication channels.

In this experiment, new forms of documentation were constructed to allow for the representation of interprocess communications information, which does not exist in purely sequential programs. Seventy-two programmers were asked to make either a data-structure or control-flow modification to each of three programs.

Substantial differences in completion time were observed among the three types of documentation formats. For both kinds of modification (control flow or data structure), the resource diagrams led to the best performance while Petri nets led to the poorest performance. Two things should be noted, though. First, the data suggest that the differences among documentation formats are not very pronounced for all cases; the text search program provided the most striking differences. Second, the modifications used in this experiment were simple and did not require many control-flow changes; this will not always be the case with modifications.

The participants' choices for the easiest to use documentation format and their previous familiarity with one of the documentation formats lead to an interesting observation. Although, overall, 68% of the programmers had used PDLs before this experiment and 71% of them chose it as the easiest to use, the time required to make the modifications with the PDLs was in between the other documentation formats, for the two types of task modification.

Taken as a whole, the data suggest that the most appropriate type of documentation for concurrent processing (resource diagram) is different than the most appropriate type of documentation for strictly sequential processing (PDL). For modifications to concurrent processing programs, at least for simple programs and simple modifications, it is not crucial whether interprocess communications or control-flow information is highlighted in the documentation format. For more complex problems, it would appear that control-flow information is not necessary, and, in fact, may interfere with making the modification. In addition, the results suggest that data-structure modifications are easier than control-flow changes.

CONCLUSIONS

Overall, the work we have done has led us to several important observations about the nature of documentation. It has shown us that the communication of control-flow information is essential in documentation for sequential programs. Given that PDLs show this type of information clearly in a way which is familiar to programmers, the research suggests that PDLs should be used more often as documentation. In fact, we have received favorable feedback from several Navy and non-military installations who have begun to use PDLs as a result of our research. Our work has also been cited by other researchers in the field, such as Atwood, Ramsey, and Van Doren, and Shneiderman.

The research further suggests that we need to be careful in generalizing our results. The final experiment suggested that the ideal form of documentation may be dependent upon the type of program being used. In this experiment, which used concurrent programs, the representation of interprocess communications information was more important than the representation of control-flow information in determining performance on a modification task.

A collateral activity conducted under this contract was the planning and production support for the Human Factors in Computer Systems Conference and its proceedings, which was held in Gaithersburg, Maryland in March 1982. The conference was a rousing success, attracting over 900 people from all over the United States and Europe. The proceedings were distributed at the conference and many more have been sent out in response to requests. In fact, the number of requests required several additional printings of the proceedings. In addition, a book of selected papers from the conference will be published in 1983 by Ablex Press, with John Thomas and Mike Schneider as co-editors. This book will include the following chapters.

Carroll, J. & Mack, R. Learning to use a word processor: By doing, by thinking, and by knowing.

This paper describes studies of learning to use a commercial word processer. Instructional materials which were designed to encourage active learning were found to produce performance which was superior to instructional materials which only encouraged passive learning. Implications for further development of training materials is discussed.

Ehrlich, K. & Soloway, E. An empirical investigation of the tacit plan knowledge in programming.

In this paper, Ehrlich and Soloway describe an experimental technique where programmers are asked to "fill in the blank" in a program from which some number of lines has been deleted. The responses made to the blank lines were used to infer what kind of knowledge is used by expert programmers. On the basis of the responses they received using a simple Pascal problem, the authors propose that expert programmers have acquired information which is chunked into "plan knowledge."

Furnas, G., Landauer, T., Gomez, L., & Dumais, S. Statistical semantics: Analysis of the potential performance of keywork information systems.

Furnas, Landauer, Gomez, and Dumais describe the results of several studies which were conducted to assess peoples' abilities to choose descriptions or names for objects so that someone else could identify that object from a set of alternatives. Their results suggest that people use a large variety of terms to describe even very common objects. The implications of this result for the viability or choice of keywords in menu systems is discussed.

Goldsmith, T. & Schvaneveldt, R. The role of integral information displays in decision making.

This paper describes a series of four experiments which evaluate the usefulness of integrating information from several sources into a holistic display. Using various types of integral displays, Goldsmith and Schvaneveldt found that the integral displays generally led to better performance than separable displays. The implications for the display of information for decision-making purposes is discussed.

Malone, T. Heuristics for designing enjoyable user interfaces: Lessons from computer games.

Malone describes challenge, fantasy, and curiosity as three features which make computer games fun. In this paper, he uses these features (derived from earlier empirical studies) to describe a set of heuristics for designing enjoyable user interfaces. These guidelines are designed to be applied to both "toys" and "tools", two distinct categories of computing systems.

McNicholl, D. & Magel, K. The subjective nature of programming complexity.

This paper describes sets of measurements which were made in an attempt to characterize the complexity of programs produced by college students. The results suggest that complexity is a highly subjective trait; students did not agree on complexity rankings for their programs. While the overall ratings suggest that program size is the best predictor of complexity, individuals' rankings were often better explained by measures of the effort required to produce the programs or by complexity rankings computed on the program specifications.

Reisner, P. Formal grammer as a tool for building usable computer systems.

This paper describes an attempt to use formal grammar as a design tool, using ROBART, an IBM interactive graphics system, as an example. The processes of incorporating "cognitive information" into the grammar and predicting performance in using the system are described. Tests of the ROBART system using the prediction assumptions are described.

Savage, R., Habineck, J., & Barnhart, T. The design, simulation, and evaluation of a menu-driven user interface.

This paper describes the design and evaluation of a menu-driven user interface. A group of participants was asked to perform a set of tasks using the interface that had been designed for the experiment. On the basis of protocols which showed what errors were made in using the system, the interface was modified and a new group of participants used the interface. The results from this phase suggested that performance, as measured by number of errors, was improved by the modifications to the interface. On the basis of this research, some guidelines for menu design are discussed.

Sheppard, S., Kruesi, E., & Bailey, J. An empirical evaluation of software documentation formats.

Sheppard, Kruesi, and Bailey describe the results of three experiments designed to examine the effects of documentation formats on the performance of programmers on different software-related tasks. Performance of coding, debugging, and modification tasks was measured by speed and accuracy measures. The results suggest that succinct symbology should be used in documentation rather than English prose. Further, presenting the information in a branching arrangement seemed to provide for the lowest overall performance times and the fewest number of errors.

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